ALDO: A radiation-tolerant, low-noise, adjustable low drop-out linear regulator in 0.35 μm CMOS technology

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1. Introduction

Starting from 2018, the LHCb RICH detector will undergo a substantial upgrade and the opto-electronic chain will be completely redesigned in order to operate at higher luminosity and rate [1,2]. New photodetectors were selected and qualified in Milano Bicocca and the Hamamatsu R11265 and H12700 MaPMTs were chosen as the baseline photodetectors [3,4]. The front-end electronics was also completely redesigned and a custom ASIC was developed for this specific purpose. The ASIC, named CLARO, has been already manufactured and thoroughly characterized [5,6].

The CLARO preamplifier needs a stable and low noise power supply since its internal references are obtained from the supply voltage and also because the preamplifier is DC-coupled to the input.

The power supply scheme currently foresees the use of the CERN radiation-hard and low noise DC/DC regulator (FEASTMP) [7] directly connected to the front-end boards. However, in order to further improve the CLARO performance, a low drop-out linear regulator could be inserted between the DC/DC regulator and the front-end chips without changing much of the opto-electronic chain layout. This approach will be beneficial both for better noise filtering and also for achieving a more stable line regulation since a linear regulator can be installed much closer to the front-end ASIC.

2. Characteristics

ALDO is an adjustable low drop-out linear regulator prototype ASIC designed in AMS 0.35 μm CMOS technology. The simplified block diagram of the chip is shown in Fig. 1. The technology chosen is the same used for the CLARO chip which proved to be able to withstand up to 1 Mrad and 1013 n eq cm−2.

ALDO can source up to 200 mA output current with an output voltage drop-out of 250 mV at full load. This will allow one ALDO to power a maximum of two front-end boards (16 CLARO chips or 128 channels) in the upgraded LHCb RICH.

ALDO features two band-gap voltage references, externally selectable by shorting the band-gap output to the error amplifier reference input. The first band-gap is designed with traditional diode-connected BJTs and is based on the AMS standard cell but with a customized layout and some schematic modifications for improving noise and stability. The second one is designed using diode-connected MOSFETs in weak inversion. This approach, even if simulations and measurements showed a lower stability over temperature, should allow us to achieve a higher radiation tolerance since MOSFETs feature a much better behavior than BJTs when exposed to high doses and fluences, as expected in the LHCb RICH environment.
For the same purpose the large area output PMOS pass transistor was designed with interleaved bulk substrate contacts for avoiding single event latchups. The chip is also protected against short circuit and over-current for a safe integration in tightly packed environments.

The regulator is externally compensated with a low ESR capacitor and achieves the best compromise of low noise and high stability with a 47 $\mu$F tantalum capacitor with 100 m$\Omega$ ESR.

3. Performance

A testboard was designed in order to evaluate the ALDO and DC/DC performance. This allowed us to test noise, temperature stability and will allow us to perform the irradiation campaign.

Noise and power supply rejection proved to be satisfying, according to both simulation results and real-world measurements: ALDO can suppress the DC/DC noise of 570 $\mu$V RMS (measured in a 10 Hz to 1 MHz bandwidth) down to less than 11.6 $\mu$V RMS. Test results are shown in Fig. 2 where the noise spectra in different configurations are plotted.

The chip was also tested in a climatic chamber to evaluate its performance with respect to temperature. The all-MOS band-gap reference generates an output voltage of 0.915 V with a temperature coefficient of $-175$ ppm/°C as shown in Fig. 3. This result is enough to meet our specifications but it was found to be worse than the value obtained from the circuit simulation. Since all the prototypes tested showed a similar behavior, it is possible to conclude that this result is not caused by devices mismatch or process variations but instead it is caused by an inaccurate parametrization of the technology model over temperature at the working point used in this design.

As expected the BJT band-gap shows a much higher temperature stability of less than 10 ppm/°C but its radiation hardness is expected to be worse. Future radiation tests will assess this and will allow us to choose which band-gap reference voltage will be more suitable for the final version of the chip.

4. Conclusion

The first prototype of the ALDO chip was designed, manufactured and tested successfully. It demonstrated to meet the specifications requested for application in the LHCb RICH detector and this will allow us to proceed in the qualification process with an irradiation campaign to quantify its radiation hardness.

References